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# FINAL PROJECT REPORT

## DEVELOPMENT OF AN EXTERNALLY POWERED PROSTHETIC HOOK FOR AMPUTEES

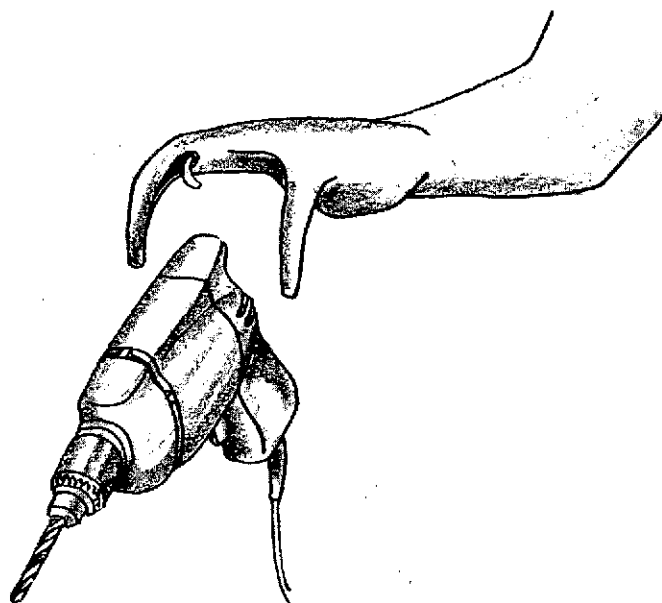
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THE ATTENDING STAFF ASSOCIATION  
OF THE  
RANCHO LOS AMIGOS HOSPITAL, INC.

Contract No.  
NAS 8 - 27020

F I N A L       P R O J E C T       R E P O R T

DEVELOPMENT OF AN EXTERNALLY POWERED  
PROSTHETIC HOOK FOR AMPUTEES

NAS 8 - 27020

COMMUNICATIONS, POWER & CONTROL ENGINEERING  
JAMES R. ALLEN, DIRECTOR

BY

ANDREW KARCHAK, JR.

JAMES R. ALLEN

ERNEST L. BONTRAGER

SUBMITTED BY

THE ATTENDING STAFF ASSOCIATION OF THE RANCHO LOS AMIGOS HOSPITAL, INC.  
12826 HAWTHORN STREET  
DOWNEY, CALIFORNIA 90242

MARCH 27, 1971 - APRIL 30, 1973

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DEVELOPMENT OF AN EXTERNALLY POWERED  
PROSTHETIC HOOK FOR AMPUTEES

INTRODUCTION

PURPOSE

The purpose of this research project was to extend the capabilities of an amputee to use a body-powered hook, through the development of an externally powered trigger finger which would be incorporated within the hook itself. Modifications in this contract extended the control capabilities for external power by developing suitable transducers and proportional control amplifiers to control this externally powered device. Work began on this contract March 22, 1971, and extended through July 31, 1973. At the beginning of this program externally powered units for the amputees were limited to electric elbows and electric hands with articulated fingers generally working in opposition to the thumb. There were no known externally powered hooks in practical use at that time.

Two types of control systems were being used: the straight switching system and the myoelectric type of controls which used surface electrodes (generally placed in the stump of the prosthesis), feeding a signal to the amplifiers which in turn powered the motor in the direction desired. At that time, there were no proportional control systems in use or transducers to activate them for the standard prosthetic appliance.

There were three major efforts made during the period of this contract. The first was to incorporate a trigger finger within the powered hook itself. The powered unit could not exceed the size and shape of the existing body-powered hook. This limitation allowed very little space to build within the frame of the hook itself an activation device that could pick up an electric drill, soldering gun, etc. which had a trigger finger control, and activate it. The second effort was concentrated on the transducers. The signal from these units required a proportional type of output, the signal for which would be easy for the amputee to provide. Most existing body-powered systems use shoulder harness motion (shoulder abduction) to operate their devices. The transducers developed under this program utilize this same motion to activate the powered hook. The third design effort was in the circuitry of the control system itself -- the proportional control amplifier. These units were required to pick up the proportional signals from the transducers, amplify them, and provide output requirements capable of driving the DC motors which operate the powered hook.

#### PHILOSOPHY

The philosophy in this program consisted of the following concepts:

1. The design itself was selected using a clinical approach when the engineer received input from both the patient and the physician.

After the basic specifications were analyzed, components were selected that would provide the performance required. The device was then bread-boarded, or fabricated in a rather rough stage, and bench tested to provide the feedback knowledge to the designer which would enable him to foresee any shortcomings in design at that point. When most of these difficulties had been overcome, a firm design of the total unit was established, fabricated, and assembled into the first initial prototype. The unit was then placed on a patient and, under laboratory conditions, observed by the designers to determine any modifications which might be necessary to improve the performance of the device. By placing the patient through a number of different activities of daily living and observing his performance, it is relatively simple to determine what changes might be required to better fit the patient's need. This evaluation is the basis for redesign, another patient test, and re-evaluation. This cycle often is repeated several times before all the problems are worked out of the system and solved.

2. Many different types of controls were investigated in both the transducers and the proportional control amplifiers, however, the basic avenues of approach were determined by the following criteria:
  - (a) The device must have a reasonable chance of succeeding within a reasonable time limit.
  - (b) The time frame used in investigating and studying each approach must be equal in all the approaches.



(c) If an item reached a point where further development required a major research effort, it would be abandoned or deferred to be studied under a major contract rather than under this short phase of study.

3. Only applied research would be used to provide design guidelines and to produce a prototype part as quickly as possible, applying engineering technology which was presently available.
4. The design of the device would be carried to the point where it was felt that it would be easy to produce industrially if necessary, however, this could not run into any major length of time. This approach requires use of on-the-shelf items which are readily and easily available in the components that comprise this type of a system, and a practical design which lends itself to machine tool production.
5. The results of this contract in the form of the final report would be disseminated widely throughout the industry so as to benefit as many patients as possible.
6. The prosthetic industry would be encouraged to use any or all of the systems or any of the components in any manner where it may be applicable to activate or control other prosthetic joints.

7. To attain widespread use, the appliance or components should be general production items which require no custom fitting to the individual.

#### ENVIRONMENT

All the research was completed at Communications, Power and Control Engineering section of the Rehabilitation Engineering Center at the Rancho Los Amigos Hospital. The Attending Staff Association of the Rancho Los Amigos Hospital, Inc. was the applicant organization and performed all administrative functions of the project.

#### Rancho Los Amigos Hospital

Rancho Los Amigos Hospital is the major chronic care facility of the Los Angeles County Department of Health Services. In addition to a large experience in chronic care and rehabilitation of numerous categories of physical disabilities, this facility has a long history of communication with and contribution to the various fields of biomedical engineering. For many years, a large population of patients with major disabilities of the neuromusculoskeletal system have been cared for at Rancho, which has provided excellent clinical and research facilities to develop an engineering program to help treat this type of patient.

Rancho Los Amigos Hospital is now affiliated with several schools of the University of Southern California School including the School of Medicine. Teaching programs are maintained on many levels of instruction.

The Hospital (Figure 1) is located in Downey, California, and is comprised of 210 acres with nearly 200 buildings. People are admitted to Rancho after disease or injury has produced a chronic disabling condition. The patient's length of stay in the hospital varies, according to his treatment program and disability. This fact produces a different environment than is found in an acute hospital where great emphasis is placed on discharging patients as quickly as possible. The conditions most frequently seen include neurological diseases with paralysis, cardiovascular diseases including heart disease and stroke, pulmonary disease such as emphysema, amputee and fracture patients, arthritics, spinal cord injured patients, and birth defects. By providing care for these disabilities along the lines of disease categories rather than medical specialities, experience and skill are concentrated on the therapeutics of each particular disability. For example, under the Department of Neurology of the University of Southern California School of Medicine, a 120-bed division of Neurological Sciences offers rehabilitation treatment to patients with disability secondary to traumatic or degenerative diseases of the nervous system. Sixty beds of the Neurological Sciences Unit are devoted to the treatment of patients with disabilities secondary to stroke. This unit has been in operation for over four years and has gained experience in the rehabilitation of more than 2,000 stroke patients. Likewise, other specialized departments, such as a spinal cord injury center, respiratory disease center, and rheumatoid arthritis center, carry out therapeutics for disabilities in these categories.

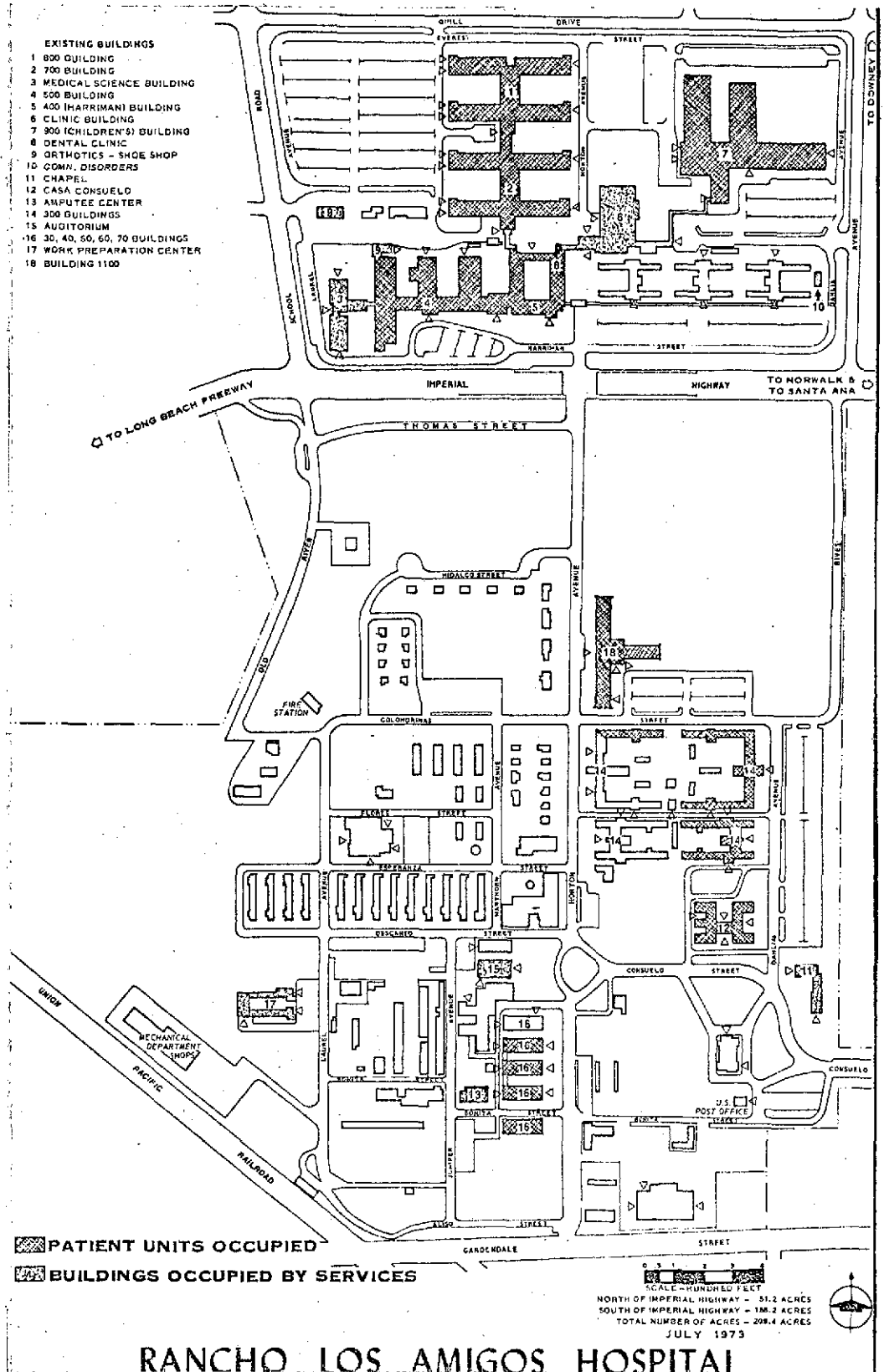


FIGURE 1

RANCHO LOS AMIGOS HOSPITAL

Rancho Los Amigos Hospital employs over 2,500 persons representing a wide range of medical, engineering, allied health, ancillary and administrative personnel. Represented among the staff are more than 220 job classifications including nursing specialties, doctors, dentists, pharmacists, psychologists, therapists, laboratory and x-ray technicians, teachers, orthotists, medical social workers, barbers, custodians, dietitians, ministers, cooks, speech therapists, ambulance drivers, prosthetists, computer programmers, clerks, welders, stenographers, mechanics, carpenters, electricians, gardeners, laundry workers, vocational rehabilitation counselors, recreation leaders, engineers, veterinarians, and specialists from various business services.

#### Attending Staff Association

The Attending Staff Association of the Rancho Los Amigos Hospital, Inc. is incorporated under the laws of the State of California as a non-profit corporation. It was organized by the medical staff of Rancho Los Amigos Hospital for the purposes of maintaining high standards of medical care, conducting medical research, and continuing professional education. The Attending Staff Association has a Board of Directors to which its Research Administrator is directly responsible for the administration of the organization's corporate affairs. The corporation maintains sound business practices for the control and expenditure of funds made available for research, including adherence to grantor's regulations for administering grant funds.

Personnel programs, systems of purchase order issue, control for purchasing equipment and supplies, fund accounting type bookkeeping, equipment inventory programs, insurance programs, timekeeping, payroll policies, and other management policies and procedures have been established. There is an independent audit of the corporation's fiscal activities annually.

Research and training are carried out under the control of the Attending Staff Association's Board of Directors and its Research and Education Committees. These activities are carried out primarily in the physical facilities of Rancho Los Amigos Hospital, via an agreement between the Board of Supervisors of Los Angeles County and the Board of Directors of the Attending Staff Association. Because of this close association with the County of Los Angeles, a policy has been established by the Attending Staff Association to parallel as closely as possible the personnel policies of the Rancho Los Amigos Hospital.

#### Communications, Power & Control Engineering

The Communications, Power & Control Engineering section (formerly the Bio-medical Engineering Facility) is a relatively new department created specifically to carry out medical engineering research in the area of upper extremity, externally powered orthotics and prosthetics. The unit has 5000 square feet of office and laboratory space. Also included are a small but unusually well-equipped model machine shop and good mechanical and electronic laboratories, a micro-miniature components laboratory and a patient fitting area.

There are eight permanent technical personnel, which includes engineers and technicians, in the department. They have acquired outstanding experience in the fitting of externally powered upper extremity orthotic devices and manipulator systems. From the previous description of Rancho Los Amigos Hospital and its various component organizations, it is obvious that the research setting for this project was unusually rich in both physical plant facilities and abundance of exceptionally trained, highly motivated personnel in the medical and engineering disciplines. The key to the many successful endeavors enjoyed by this hospital is the great enthusiasm and cooperative spirit which pervades the entire hospital complex.

#### ACCOMPLISHMENTS

The successful attainment of the goals of this contract resulted from the combined and individual accomplishments made during the process of carrying out the project. These accomplishments included device development through special investigation, patient fitting, and dissemination of information.

The entire contract involves four distinct phases which are reported chronologically as they occurred.

#### PHASE I

At the beginning of the program it appeared most logical to purchase some equipment in order to learn something more about the problems inherent in these tools.

At least two tools of a triggering action were required, so a 1/4" Black & Decker electric hand drill and a Weller soldering gun were selected. For an activation device, it was felt that initially that we could use a standard prosthetic hook with a body-powered trigger finger mounted on it. Fitting this unit on an amputee in the laboratory might reveal more about the problem. As planned, these items were purchased and a trigger finger was mounted on a standard hook. No attempt was made to conceal the mechanical linkage which consisted of a spring loaded mechanism that activated the trigger by the use of body power. Shoulder abduction of the harness pulled on a cable which released the trigger and then opened the hook. This unit was fabricated and worked well enough to pick up a drill and actually use it in a drilling operation. Even though the unit worked very well for drilling and soldering, it was unsuitable to try to use a device of this type for just holding the unit while the mechanism was not being electrically activated because it required body power to hold the trigger in the "off" position. This required expending human energy in a "hold" position, however, the instrument was useful to obtain certain types of information such as determining the holding power required to maintain good stability of the tool and at what force the triggering should occur. When this unit was applied to the patient and actually used clinically, we determined that approximately 15 pounds of prehensile force would be necessary to hold firmly either the drill or the soldering gun, and that an additional ten pounds of prehension probably would be necessary for the triggering element. This placed our total prehensile force at about 25 pounds of activation force by the power unit.



The next step consisted of designing the hook portion of the unit. The configuration was based on the curvature of the body-powered hook and consisted of two parallel strips of aluminum which were bent in the same shape as the hook with spaces in between which would permit an installation of the triggering mechanism. The initial power unit selected was a 12-volt motor consisting of the armature and one stage of a 4:1 spur gear reduction which was housed in a 3/4" body diameter. The entire motor unit itself was 1-1/4" long. An additional 47-1/2:1 reduction was placed in the gear mechanism of the hook. This consisted of a 10:1 worm and a 4:75:1 spur to give the final drive reduction. When this prototype design was fabricated, assembled, and laboratory tested (See Figure 2), it was found that the total prehensile force was in the neighborhood of three pounds at the terminal device. This meant that an additional force requirement of a factor of at least ten might be necessary to perform the required tasks. The total overall efficiency of our present reduction system appeared to be less than 20 percent, so it was decided that, in order to keep the motor with the gear head unit as small as possible, it would probably be necessary to incorporate an automatic transmission within the unit which was sensitive to load. In this manner the unit could move at a fairly rapid speed at no load. General speed requirements from full opening to closing should be about one second. At a point where the demand for torque increased due to the presence of an object between the fingers, the unit could reasonably shift down to a greater reduction, probably an additional 5:1 or 6:1 since force and not displacement is the primary consideration at this time.

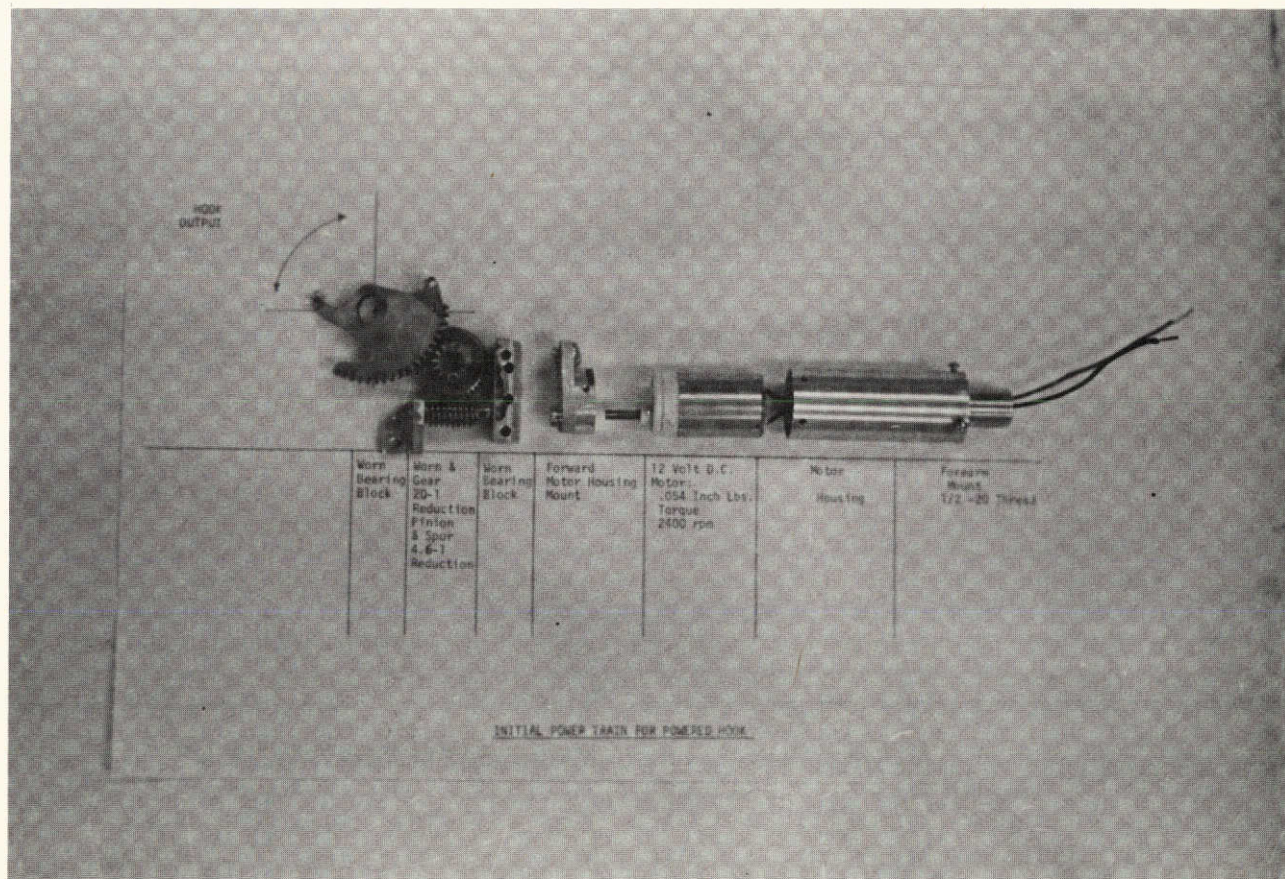


FIGURE 2

INITIAL POWER TRAIN FOR  
POWERED HOOK

After a careful search it was decided to use the same motor and automatic transmission that Otto Bock had developed for their electric hand unit and is shown in Figure 3. The entire hand unit was purchased; the motor and automatic transmission were removed and inserted into our present device. The next step was to determine the mechanism to use within the space available for the rotating trigger finger to perform its triggering action. After studying the problem carefully in the space available, it was determined that a sliding cam arrangement which required approximately 1/2 inch of linear motion would perform this required motion. The initial 1/4 inch would have to rotate the finger approximately 90 degrees and then a straight sliding action for the second remaining 1/4 inch would activate the trigger. A sliding cam motion was fabricated and inserted within the trigger finger unit (Figure 4). The drive system linkage of the motor now required a spring loading within the prehensile mechanism capable of providing a maximum prehensile force of 25 inch pounds of torque in order to provide sufficient grip on the power tool.

As the motor increased the gripping torque, the drive system allows an additional rotation of 25 degrees under a spring load which has its angular motion translated into a linear trigger finger actuation. A spring was selected that met this requirement and built the prehensile force up to the approximate 15 pounds, and then allowed an additional displacement to trigger the finger. The last portion of the design included the linkage between the rotating trigger finger and the power unit itself.





FIGURE 3

OTTO BOCK TRANSMISSION USED FOR

POWERED HOOK

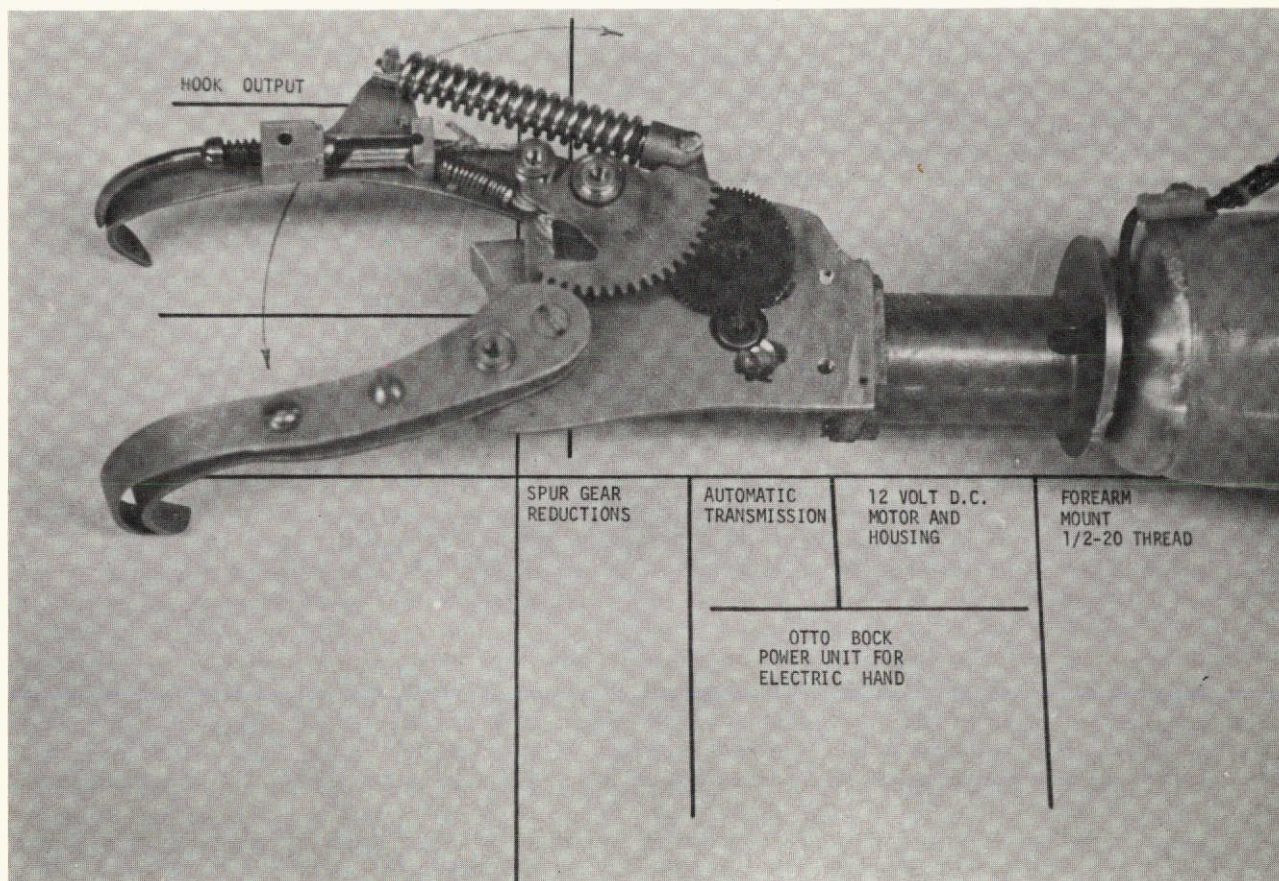


FIGURE 4

SLIDING CAM MOTION - TRIGGER FINGER

UNIT



While a metal linkage was desirable, due to space limitations, it was difficult to incorporate. The space available within the hook to place this mechanism was approximately .375 cubic inches. The final linkage required a material capable of at least 30 pounds of tensile force which could bend around a 1/4 inch diameter pulley. This small pulley size eliminates most metals, even finely woven cables. Monofilament line of reasonable size, as used for fishing lines, tends to creep while continuously loaded. Two types of linear line used by fishermen were tested. The first type appeared as a standard type of weave used to make any type of string. This tested out at about ten pounds of tension with a stabilization in creep after a few hours. This could not be used on the hook because its tensile strength was too low. The second type was a tubular helical weave with a tensile strength of 20 pounds. This line was doubled; when inserted into the hook and cycled about 30 times, it appeared to work well enough to perform some preliminary laboratory tests on the unit.

After about an hour of laboratory testing, we ran into some gear problems which required a modification in the gear system. The first gear cluster, which comprised the first two stages of reduction from the motor and the automatic transmission, was built of standard off-the-shelf brass Boston gears which showed severe wear in a short period of operation. A new set of gears was cut from 17 PH series of stainless steel which combined good corrosive resistance with high tensile strength.

Additional clinical testing was done on the unit at this point. This evaluation elicited the following good and bad features of the unit:

1. The motor with the automatic transmission performed extremely well.
2. The gear reduction and hook structure appeared to be satisfactory in its present state.
3. The trigger finger mechanism using the sliding cam performed satisfactorily. (Some additional testing will be necessary to make a final determination on this unit.)
4. The mechanical linkage of the trigger finger to the gear mechanism was not satisfactory.

The 30 pound test Dacron line used was not strong enough to completely activate the trigger finger. A mechanical stop was also placed in the mechanism to try to protect the linkage when it had reached its end point so that it would not be pulled to fracture. The size of the Dacron line in the mechanical linkage was now increased to a 50 pound test. After a number of laboratory and clinical evaluations, the unit appeared to work satisfactorily. At this point, it was decided to produce four additional units for prototype testing. During the fabrication of these next four units, additional clinical application of the hook was made with a patient performing drilling activities.

The activity for the documentation of the triggered finger included drilling holes in a piece of wood. One hundred feet of 16mm film was consumed showing this operation. Some of the original detail and assembly drawings were begun during this time and have continued in the documentation of the mechanical design of the device.

Some additional improvements were made at this time in the patient fitting. A permanent axilla loop harness was fabricated using shoulder abduction to control the unit. At this point over 200 cycles of satisfactory performance had been achieved with the device. The last step in development was to build a cosmetic prosthetic glove for the unit. The Kingsley Manufacturing Company in Santa Ana was contacted and they agreed to build a plastic mold that would provide the glove required for the unit, so work began on building this cover.

After the four models of the powered hook had been fabricated and assembled, one sample of the glove was submitted for approval which appeared to be satisfactory. Twelve gloves were ordered, six each for the right and left hand units and are shown in Figure 5. Two permanent prostheses were fabricated for future patient testing. An additional set of solid hooks was fabricated which did not incorporate the trigger finger so we could evaluate both the hook as a powered unit without the trigger finger and the standard trigger finger unit. The units were built so that they were interchangeable within the same powered device. At this point, the patients were completely fitted with the two powered prostheses with the shoulder harness; the new sockets with the trigger finger unit were attached and wired with the control system and are shown in Figures 6 and 7. A number of clinical evaluations were made in actual testing and performance in the laboratory and were properly documented. At this point, Phase I of the Powered Hook had been completed and the project continued without interruption into Phase II.



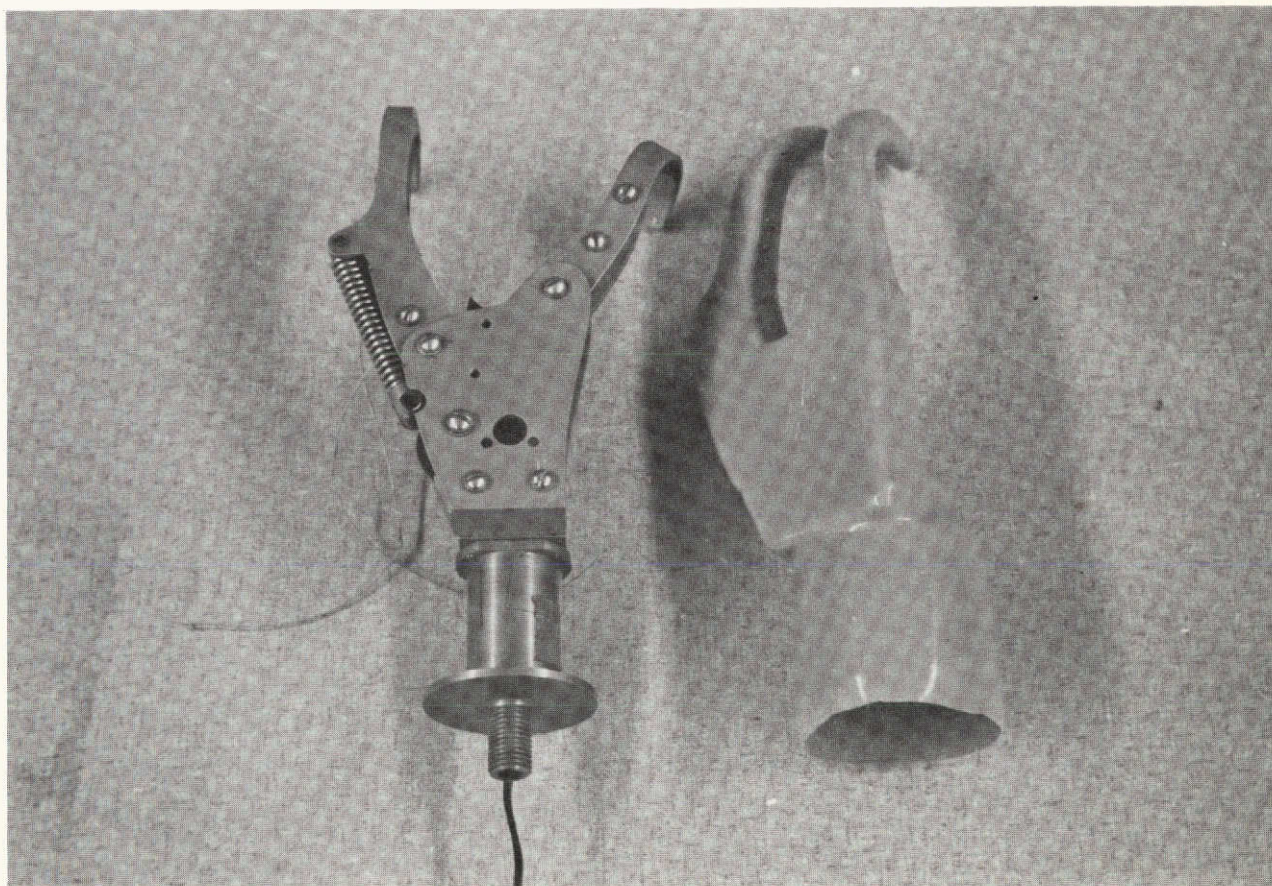


FIGURE 5  
POWERED HOOK AND COSMETIC PROSTHETIC GLOVE

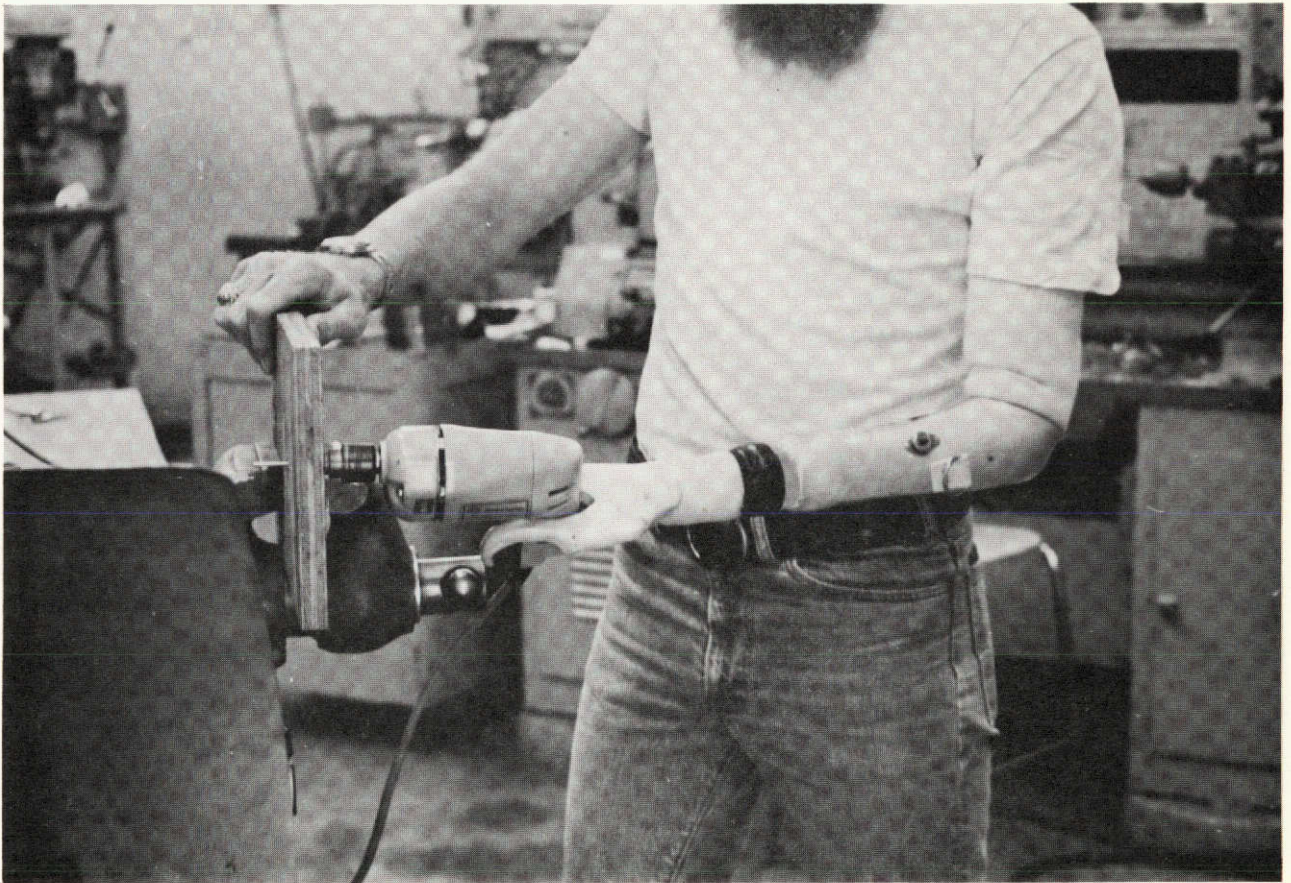


FIGURE 6  
POWERED HOOK AND TRIGGER FINGER IN  
DRILLING ACTIVITES



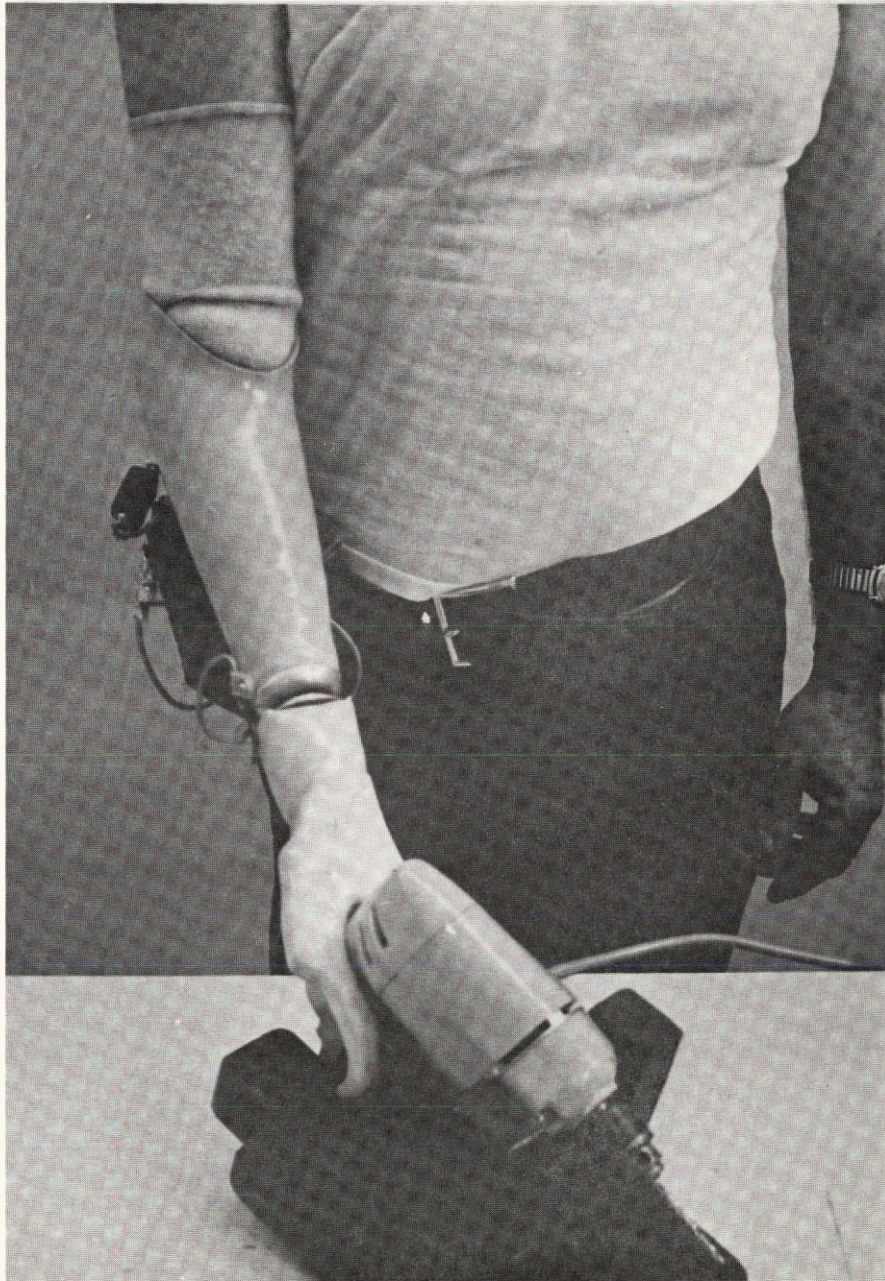


FIGURE 7

POWERED HOOK & DRILLING TOOL

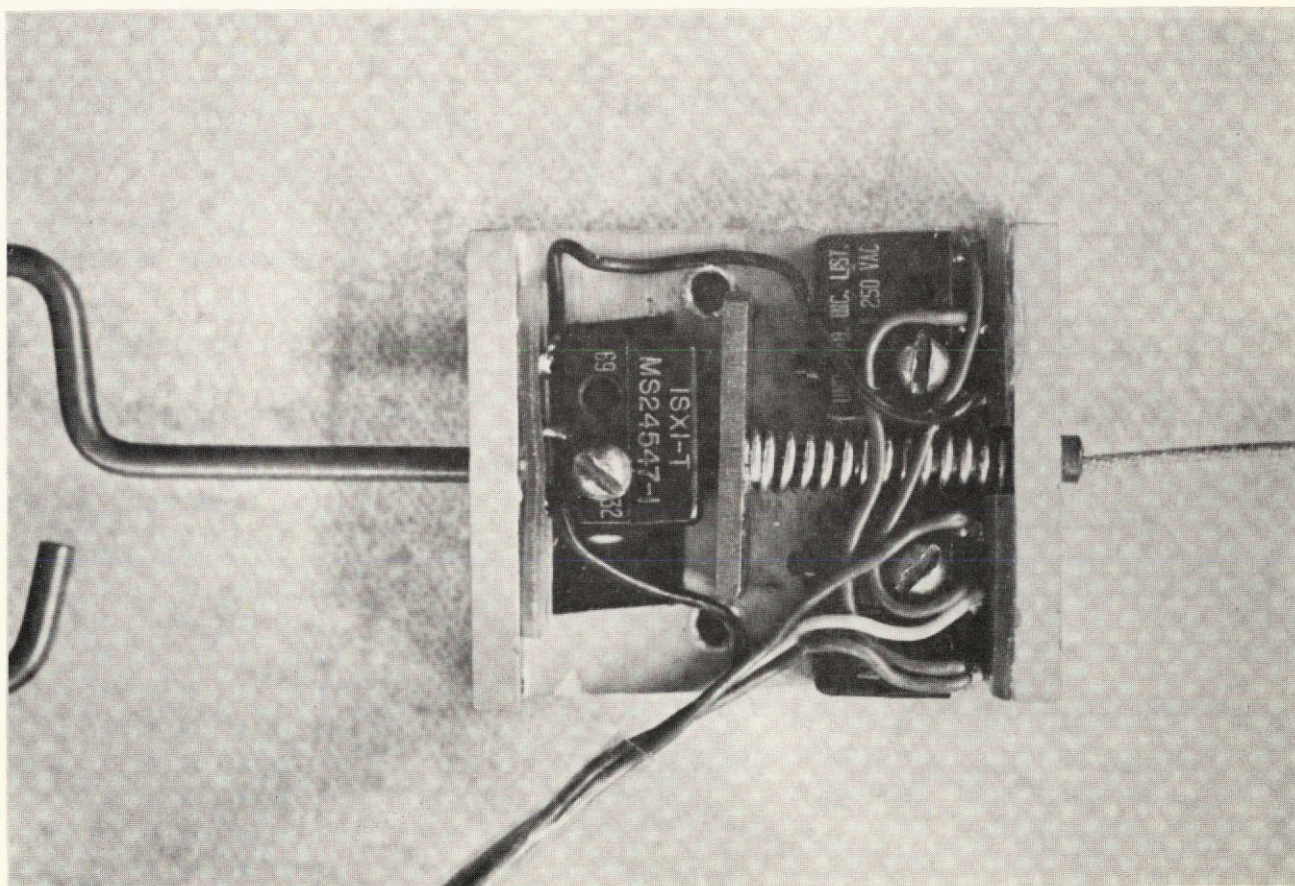


FIGURE 8

SHOULDER HARNESS

ON-OFF SWITCH TRANSDUCERS



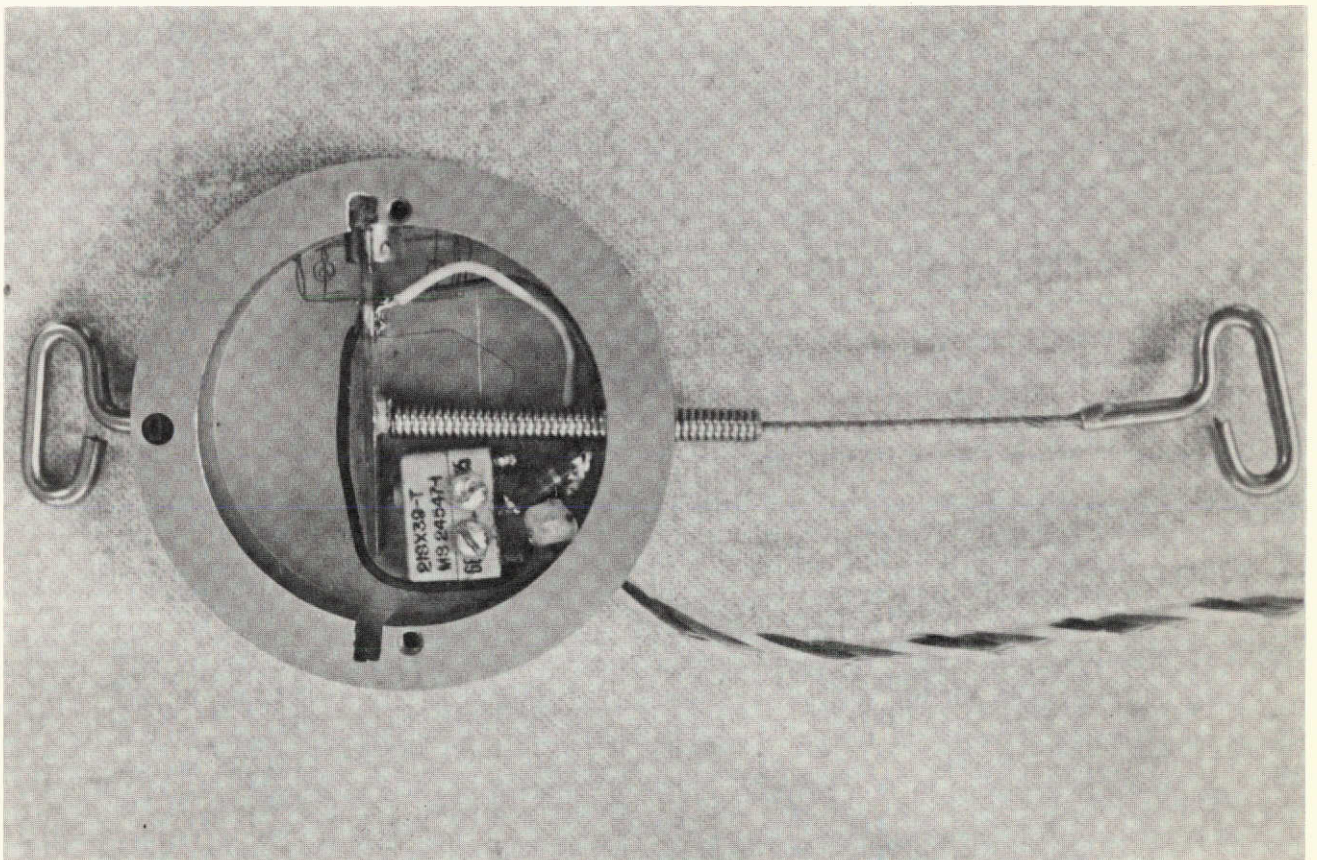


FIGURE 9

SHOULDER HARNESS

CANTILEVER BEAM TRANSDUCER

## PHASE II

During Phase II more effort was directed to the control problem.

Conventional prostheses utilize motion such as shoulder elevation, abduction, chest expansion and, more recently, myoelectric sources to open and close switching contacts. Of greater value during this phase were transducers and amplifiers capable of giving the patient volitional proportional control. These were within the realm of existing technology and were pursued for the powered hook control. Bench testing of the device continued for several hundred cycles, when an interference problem occurred on one of the pulleys. This interference was not apparent in the prototype unit. Investigation indicated that it would be necessary to change the contour of the pulley, which would probably require about an extra man-day to modify the present four models. This correction later proved highly satisfactory and worked well.

Attention turned toward the physiological transducers which would be required to control the powered hook. Available transducers of this type, whether used in prosthetics or orthotics, generally use some extremity motion when activated which displaces linearly relative to some other part of the body. This linear motion is then used to control an appliance. It was decided to design and build two units of this type for testing. One would be an on/off switch type; the other would be a strain gauge fixed to a beam capable of providing a proportional output. These are shown in Figures 8 and 9.

Amputees generally like at least four to five pounds of control pulling force. This avoids accidental activation and provides firm physiological feedback. Simultaneously, it was decided to design and build a basic proportional control amplifier that would fit the need for the amputee. Weight and size ultimately would be of utmost importance, not only for the amplifier, but also for a rechargeable battery pack which the amputee would require. After several weeks of design and fabrication, a complete system was assembled. This system consisted of the powered hook with the trigger finger, a proportional transducer, a proportional amplifier, two nickel cadmium battery packs, and a special battery charger capable of charging both the power supply and the proportional control energy sources. The amplifiers and battery were housed in a leather case with a belt that could be worn around the waist. These are illustrated in Figure 10.

Most of these units were larger than optimum for this type of use, but they would be adequate for the first prototype and for patient testing. The results of this initial prototype of a completed system fulfilled the requirements of Phase II of this program and as before, Phase II continued to Phase III uninterrupted.

### PHASE III

The initial concept of Phase III of this program was to build and distribute for clinical evaluation five proportional control systems (other than the one at Rancho) to centers throughout the country.



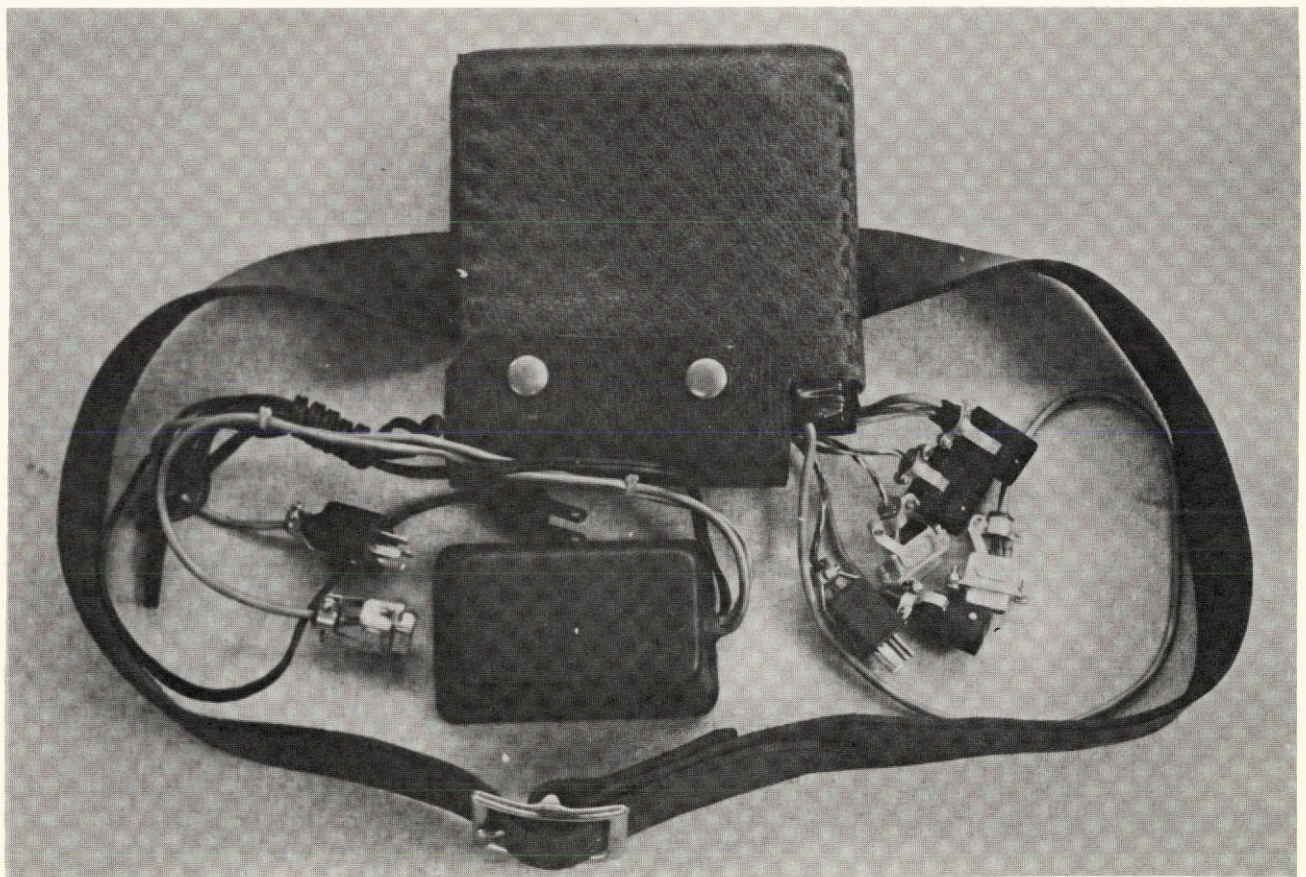


FIGURE 10

PROPORTIONAL CONTROL AMPLIFIER

BATTERY, CHARGER & BELT



Since only four single units were available and one would have to stay at Rancho as backup equipment, the plan was altered so that only three units were sent to other institutions; the remaining multichannel unit would be evaluated at Rancho. The hook on an amputee and the multichannel for an orthotic purpose on Celeste Thompson (a poliomyelitis victim) would be evaluated.

The proportional control units were now all miniaturized, redesigned, and refabricated for the clinical evaluations which had been planned. During the next six months of the program, the single and multichannel proportional control units (amplifiers) were redesigned and repackaged, and were given several tests. Two different amputees were used at Rancho to evaluate the components of the entire system. Both individuals required very little training and were capable of picking up the drill and drilling holes in either the vertical or horizontal position quite successfully. These activities were photographed and documented for future reference. As bench testing of the powered hook itself continued, it was found that the fifty pound test Dacron line which was used in the linkage between the trigger finger and the power unit was failing after 2000 cycles. This occurred about four times during the bench testing which is shown in Figures 11 and 12. It was determined at this point to increase the size of the Dacron line from a 50 pound test to a 130 pound test which was the largest size available that would still fit within the mechanism itself. The multiple channel amplifier with 14 channels was fitted to Celeste and was clinically tested on her in our facility.

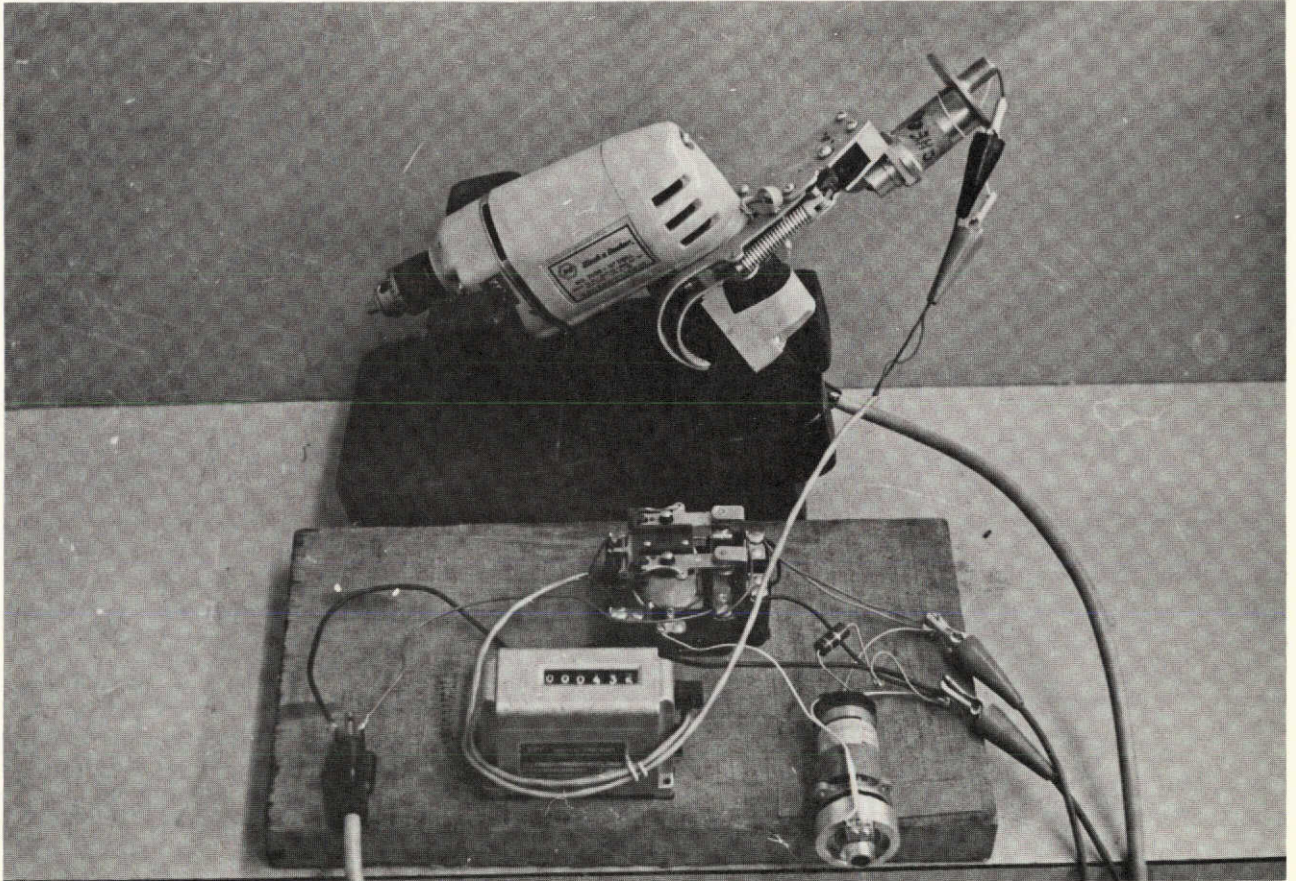


FIGURE 11  
BENCH TEST



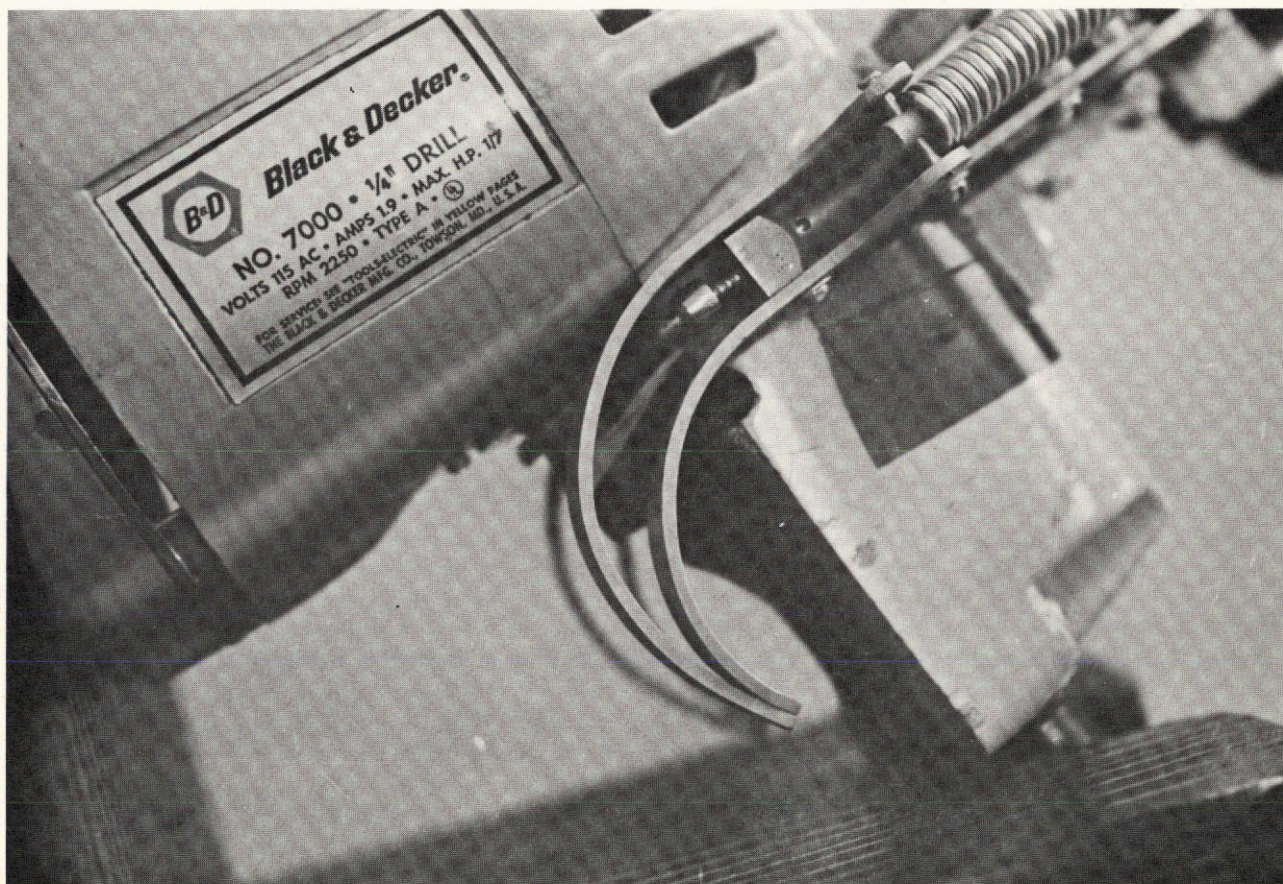


FIGURE 12

TRIGGER FINGER ACTIVATING

ELECTRIC DRILL

This equipment worked successfully; with it, she could, for the first time, perform tasks which she had not been able to do up to this time with the conventional system. Since most of the installation was of a breadboard type nature, it was decided to now package the unit in a permanent set-up for her wheelchair, making it portable. Meanwhile, four additional units, which were all similar, were tested, evaluated and given their final inspection. These three units were sent to previously chosen centers -- The Veterans Administration in New York City, the Burke Rehabilitation Center in White Plains, New York, and the Army Rehabilitation Center at Walter Reed Medical Center in Washington, D.C. The units were sent with instructions on how to operate the equipment and with guidelines for the evaluation. Thirty days were allowed for this testing but this proved too short so a request was made to extend the period of the contract for an additional sixty days so that these tests could be completed. Meanwhile, Mrs. Thompson was fitted with her unit completely, shown in Figure 13, and plans were made to have her visit Washington, D.C. to demonstrate her complete unit before the group at the Walter Reed Medical Center in Washington, D.C. This visit would constitute Phase IV of the project.

#### PHASE IV

For Phase IV of the contract, Mrs. Thompson's fitting was completed and well tested within the laboratory by several visits to the facility and checkouts that included several hours of actual clinical evaluation. After testing was completed, preparations were made for the trip to Washington, D.C.





FIGURE 13

MRS. CELESTE THOMPSON WITH COMPLETE  
PROPORTIONAL CONTROL UNIT

This planning involved many difficulties since it was the first attempt ever made by personnel at Rancho to transport a quadriplegic from one end of the country to the other, and arrange for all the back-up equipment and conditions under which she could make the trip. Special arrangements were made with United Air Lines to install a special power supply for her breathing equipment which was placed under one of the forward seats. A block of six seats was reserved for Mrs. Thompson, her attendant, and two engineers who accompanied her on the trip. In addition to the power supplies for her breathing equipment, two batteries were transported for emergency situations and a final back-up was a hand-powered respirator that could provide adequate respiration function should all other systems fail. Transportation arrangements were required at Los Angeles and Washington, D.C. to provide a vehicle large enough to transport Mrs. Thompson in her electric wheelchair, along with all the additional equipment which she would require to stay overnight or for several days in Washington, D.C.

The demonstration was made to the representatives of the Walter Reed Medical Center and was most successful and is shown in Figure 14. Celeste was capable of performing well in all activities such as stacking blocks quite high, precariously balancing them one on top of the other. This indicated the fine degree of control provided by this new device. While in Washington, Celeste visited the Rayburn Building, where the Congressional Committee which allocates funds to the Technology Utilization section of NASA, was in session. Celeste also demonstrated her device to them.



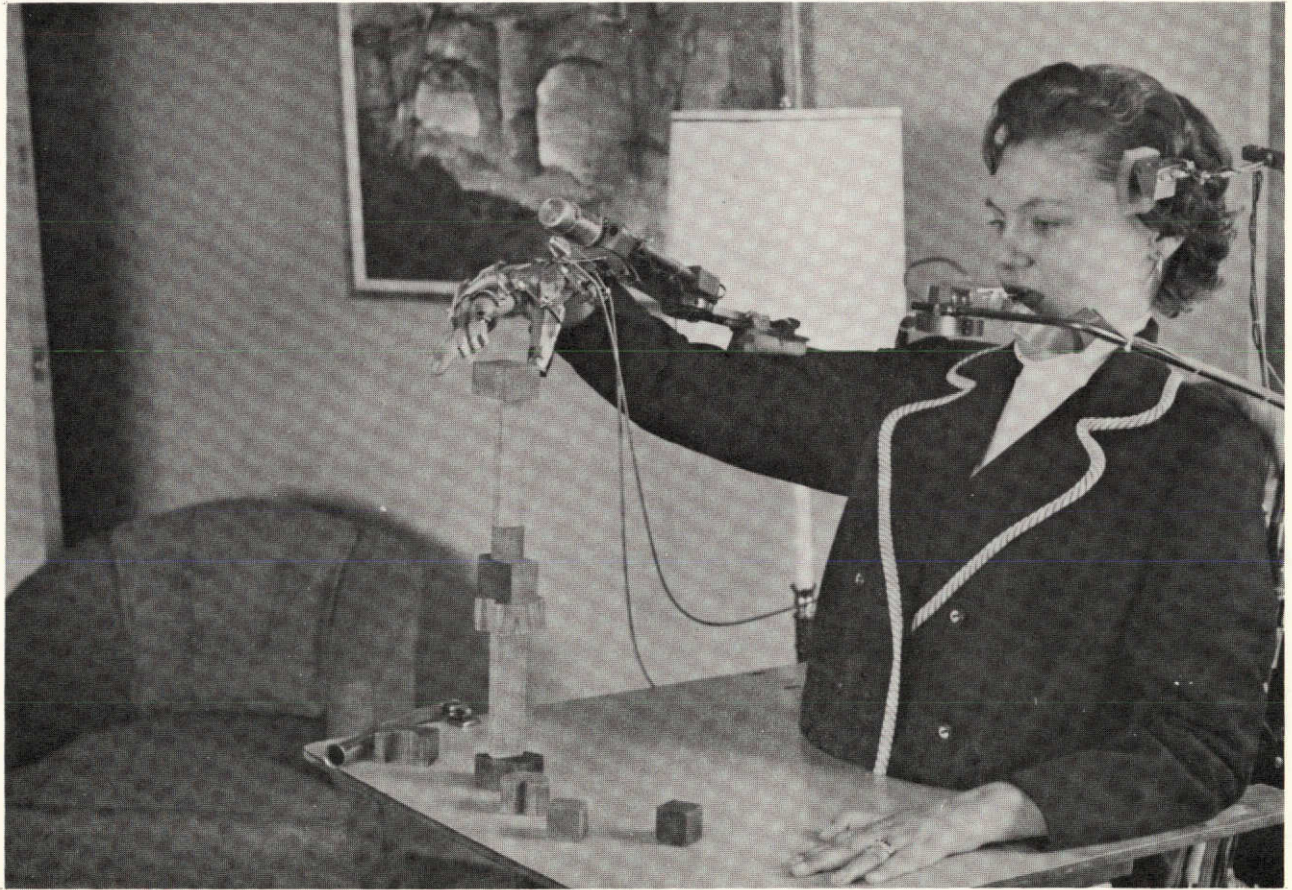


FIGURE 14

MRS. CELESTE THOMPSON DEMONSTRATING PROPORTIONAL  
CONTROL

In Figure 15 she is discussing her fitting with Congressman Teague. During her stay in Washington, D.C., she was given an opportunity to visit the White House through special arrangements made by the NASA Technology group. She had a private tour of the White House itself (shown in Figure 16) which she enjoyed immensely.

After five days in Washington, D.C., the group returned to Los Angeles. During this entire time, everything functioned well, with no mishaps. Mrs. Thompson felt that she never could have made this trip under any other circumstances. She was thrilled and enjoyed it very much. It appears that all the people who saw her demonstration in Washington, D.C. were equally pleased with her performance.

Several news releases were made on this trip and were published in national and local newspapers. As a result of this trip and demonstration, it was decided to continue into one additional phase (Phase IV) which would include another fitting similar to Mrs. Thompson's. At this time, a patient is being selected at Rancho Los Amigos Hospital who will be a candidate for the Electric Arm. This patient will be fitted and clinically evaluated with the same proportional control system.

The final proportional control amplifiers, shown in Figure 17, as used on Mrs. Thompson, fittings are mounted on a plug in circuit board and are well-miniaturized lending themselves ideally for ambulatory use.





FIGURE 15

MRS. THOMPSON SPEAKING WITH CONGRESSMAN TEAGUE



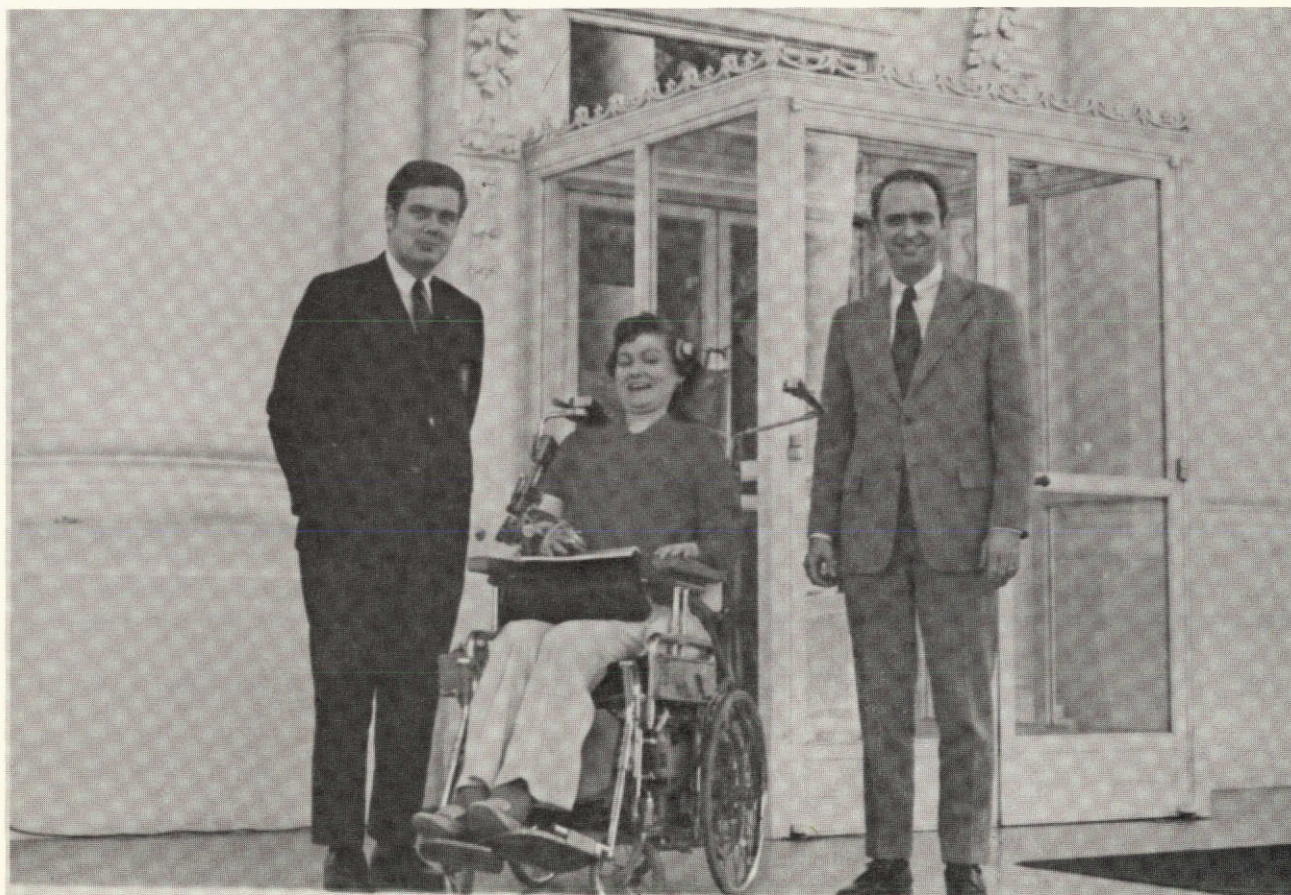


FIGURE 16

MR. JOHN HAMBRICK, U.S. SECRET SERVICE WITH  
MRS. CELESTE THOMPSON AND MR. MICHAEL FARRELL,  
PROTOCOL OFFICER, IN FRONT OF THE WHITE HOUSE

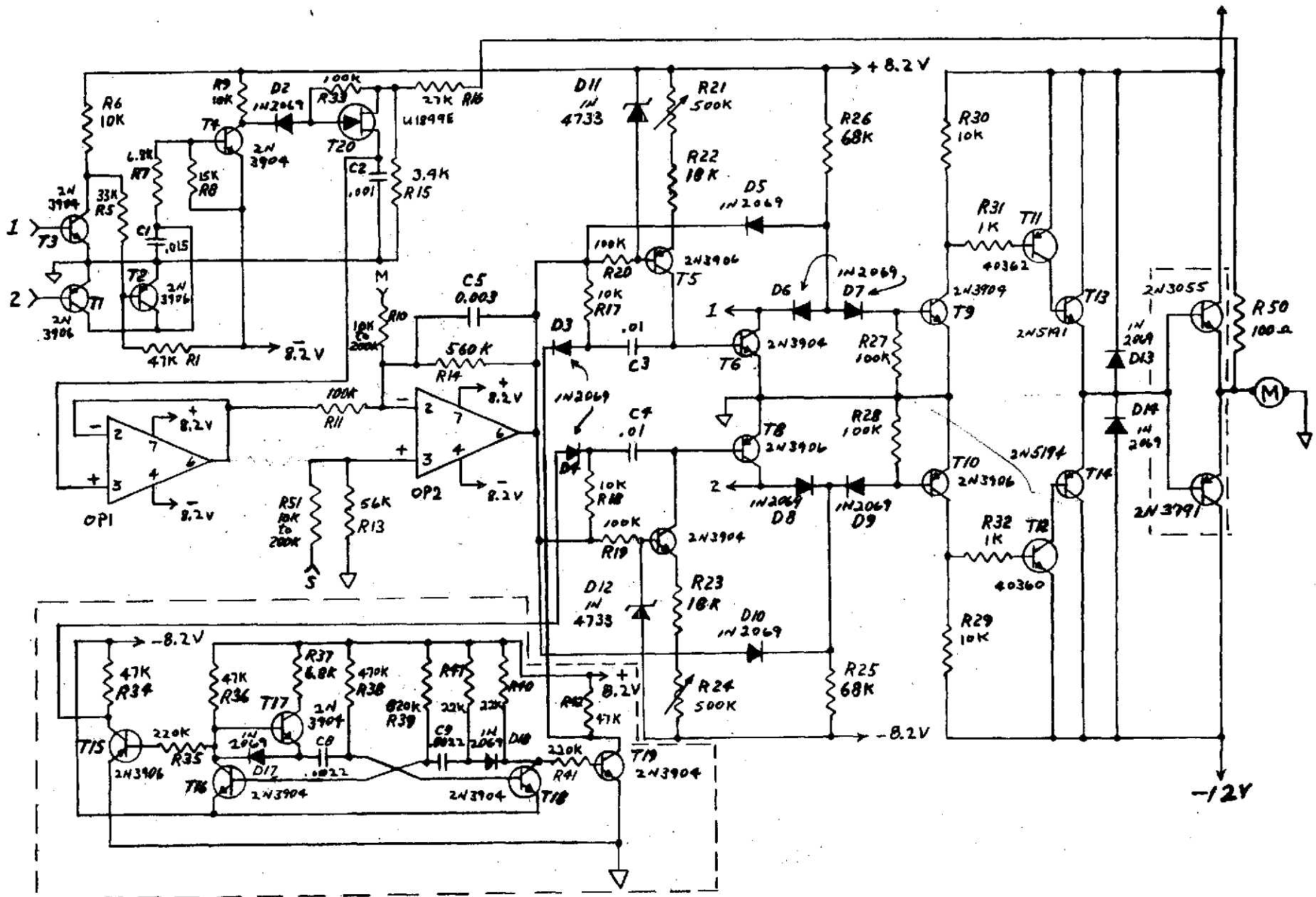


Figure 17  
CIRCUIT DIAGRAM OF PROPORTIONAL CONTROL AMPLIFIERS  
PULSE WIDTH MODULATOR, MOTOR CONTROL

### Patient Fittings

The following patient fittings and evaluations were made at the Centers previously indicated. The initial letter of transmittal, along with the guidelines, procedures and equipment operation instructions, are included in the appendix. The first of these reports is presented in its entirety and was submitted by Mr. Frederick W. Werner, Department of Bioengineering, The Burke Rehabilitation Center in White Plains, New York.

THE BURKE REHABILITATION CENTER  
WHITE PLAINS, NEW YORK  
10605  
WHITE PLAINS 8-0060

N.P.

This patient is a 28 year old salesman who incurred a fracture dislocation of C5-C6 in a diving accident on July 23, 1972. His functional status is C6 quadriplegia with a C5 sensory level. He has no hand function at all. There is dull sensation in his hands in the ulnar distribution, with somewhat better return of sensation in both arms and index fingers.

We originally made a tenodesis splint for his right hand, But when he developed contractures in the fingers of both hands, he was unable to overcome them. Because of this we manufactured an electric hand orthosis, powered to open his right hand. A mechanical stop prevents the excessive pain which would be caused if his hand were opened too far. Prehension is brought about by the contracture of his hand in conjunction with a spring assist. He has used this orthosis during the latter part of his hospital stay.

We discussed with his occupational therapist which tasks would be most appropriate for N.P. They are concentrated in the activities of daily living, and include using a telephone, writing with a Flair pen, using an electric shaver and manipulating "Hi-Q" pegs (small 1/4" diameter pegs). Due to the tightness of his fingers and the design of his orthosis, he is unable to securely grasp a conventional coffee cup or mug.

N.P. was able to complete all tasks with greater or equal ease with the proportional control as compared to the on/off control. This was demonstrated especially with the "Hi-Q" pegs, which he was able to easily remove and replace from and to the pegboard because of the fine control. In contrast, he had little success with the on/off control, except with widely isolated pieces. Because he could slowly adjust his hand position with the proportional control, he was able to more securely grasp the telephone receiver, the electric shaver and the Flair pen than with the on/off control. In order to grasp the telephone, he had to open his hand almost to its maximum. With the proportional control, he could approach that point more slowly than with the on/off control, with which he had difficulty in fully opening his hand at all times. Whereas N.P. was able to handle the electric razor equally well in both control modes, due to its large rectangular shape, he was able to write more legibly with the Flair pen while using the proportional control; again due to the better and finer positioning of his hand. Because the tasks performed are within the area of ADL, we did not feel that time and/or accuracy was as important as whether or not a specific task could be successfully completed. Being an easily frustrated individual, N. P. would not complete a task which appeared to demand a relatively long period of time.

To summarize our results, N. P. could better position his hand with the proportional control. Using the on/off control, he sometimes felt he had to go through much of the entire cycle if he failed to place his hand as he desired. He liked the slow, exact control possible with the proportional control, but also appreciated the more easily attained fast hand speed of the on/off control.

N. P. is not a mechanically oriented individual (as was evidenced by the difficulties he experienced in learning to drive his electric wheelchair). Nonetheless he adapted quite readily to the proportional control, which suggests that the interests and aptitudes of a given individual do not prevent his becoming quickly accustomed to the device. While working with the on/off control, N. P. supplements his visual observation of the task by listening for the sound of the clutch slipping. (There is a slight but detectable difference in sound when the clutch is or is not slipping) N. P. could not apply his auditory sense to the proportional control.

N. P. did have a serious problem, peculiar to his disabled state, with the proportional control. When nearing the point of maximum opening, he required increasingly more power to overcome the force of his contractures and the spring. The substantially additional lever force required proved frustrating to him. As a result he appreciates the constant lever force of the on/off control for gross hand motions. (He has periodic fluctuations in finger tightness so that the mechanical stop could not always protect him from pain and simultaneously allow as wide a hand opening as possible.)

Finally, N. P. occasionally encountered surges of power upon the immediate release of the proportional control lever after trying to open his hand as far as possible. I was only able to duplicate this phenomenon once, and am still unsure about its cause. I believe it happened only when the batteries were not fully charged.

#### R. C.

The patient is an 18 year old carpenter's helper who incurred an on-the-job accident on June 2, 1972 when a wall collapsed, striking him. It was found that he had a fracture-dislocation of C5-C6. Because of presumed instability, an anterior fusion was performed on July 7, 1972. His prehension on the right is trace; on the left, zero.

As R. C. has a tenodesis splint, and as no powered device was prescribed for him, I was interested in his trying a worm-gear drive prehension orthosis. The worm-gear drive provides power in both opening and closing his hand.

R. C. performed several tasks similar to those of N. P., with the addition of objects requiring a larger grasp. The tasks included using a telephone, manipulating "Hi-Q" pegs, writing with an ink pen and grasping various coffee mugs and cups.

As R. C. did not have previous experience with an on/off control, I was able to compare how a patient might respond initially to both control systems. There was slight improvement in fine grasp using the proportional control as compared to the on/off control; the patient feels the proportional control provides more "stability". Other than greater stability, he did not demonstrate a radical difference in the ability to position his hand, as had N. P.

There was virtually no difference in performance in the completion of tasks involving the telephone, pen or coffee mugs. There was a slight improvement over the on/off control in using the proportional control to manipulate the "Hi-Q" and other sized pegs.

R. C. adapted easily to each control system, but especially to the proportional control. As was the case with N. P., he had difficulty in attaining high speeds with the proportional control due to the relatively large force required on the transducer lever. Because of the gearing and the motor of the worm-gear system, the hand opened and closed at a slower speed than N. P.'s cable driven orthosis (compared by using the on/off control). This fact, in conjunction with R. C. having slightly better hand function than N. P., may explain why R. C. did not experience as dramatic an improvement as N. P. did while using the proportional control as compared to the on/off control.

### Summary

We found the proportional control especially helpful in the fine positioning of an electric hand orthosis.

The transducer lever and control system should probably be redesigned or adapted to enable the patient to attain higher speeds more easily. This might be accomplished by developing appropriate support mechanisms for the transducer or by investigating other lever activating sites.\*

\*We may have had a problem peculiar to the lever activating sites we chose. In both cases, the contralateral hand exerted a sideways force on the transducer. N. P. occasionally placed the lever between his third and fourth fingers.

The next report was submitted by Mr. Tom Pierrello of the Veterans  
Administrations in New York City





VETERANS ADMINISTRATION  
HOSPITAL  
CASTLE POINT, NEW YORK 12511

VA VOLUNTARY SERVICE  
1946-1971  
25 Years of Service  
to Veteran-Patients

July 25, 1973

IN REPLY  
REFER TO: 117

Mr. Andrew Karchak, Jr., Project Director  
Communication, Power & Control Engineering  
Rancho Los Amigos Hospital  
12826 Hawthorn Street  
Downey, California 90242

Dear Mr. Karchak,

Mr. William Hardy was fitted with the Rancho Proportional Control system on July 12, 1973. He is a 23 year old, C-4, C-5 level quadriplegic injured in a car accident in February, '69. Mr. Hardy is presently discharged from the hospital.

He has used a Hosmer control system since 1970 with parallelogram BFO, and finger flexion orthosis.

He was able to grasp and release various size and textured objects with the Rancho Proportional Control system.

The control system worked well for 5 to 10 minutes, and then became increasingly difficult to activate in flexion and extension, but particularly in extension, requiring considerable pressure on the actuating lever. Despite several adjustments to improve the function, we were unable to correct the problem.

We feel that the difficulty is with the transducer rather than the amplifier; that the basic idea of proportional control is good, but wish that it could also be applied to extension.

Sincerely,

Jacqueline Gayer  
Chief Occupational Therapy

for  
Mr. Thomas Pirrello

The final report was submitted by Mr. Lloyd Salisbury of the Army

Rehabilitation Center at Walter Reed Medical Center in Washington, D.C.



US ARMY MEDICAL BIOENGINEERING RESEARCH & DEVELOPMENT LABORATORY  
FORT DETRICK, FREDERICK, MARYLAND 21701

MR 26-73

MEMO THRU: <sup>Wade</sup> Dr. C.W.R. Wade, Actg Chief, Biomats & Eval Div  
TO: Mr. L.L. Salisbury, Chief, Biosystems Control Branch  
FROM: John W. Hodge, Jr., Actg Chief, Engr Eval Branch  
SUBJECT: Evaluation of El Rancho (Prosthesis) Control System  
DATE: 25 Oct 73

I. INTRODUCTION

A control system designed to operate an electromechanical upper extremity prosthetic device for either an above elbow or below elbow amputee, was submitted for evaluation.

This system was developed at El Rancho Los Amigos Hospital, and consisted of a cable actuated proportional control switch and a pack containing batteries and the electronic circuitry. The batteries were rechargeable nickel-cadmium with a 12 volt capacity for operating a motor.

The control was evaluated on a below elbow prosthesis equipped with a USAMBRL electro-mechanical hand. The control switch was mounted on the forearm socket and operated with half of a figure of 8 harness.

The switching arrangement in this system was based on a proportional control concept. A light pull on the control cable caused the motor in the terminal device to run slowly. An increased pull caused a corresponding increase in motor speed. At some maximum pull a microswitch within the control switch was activated and caused the terminal device to open.

II. PROCEDURES

The control system was checked for size, weight, operation on an amputee, and general observations were made that might effect overall performance on and off the amputee.

Cable forces required to initiate action were determined by placing weights on the operating cable sufficient to cause very slight movement of the motor shaft. Maximum cable force, resulting in maximum speed to close the terminal device, was determined with a Hunter spring scale graduated to 1/4 pound. The maximum cable force to cause switching for opening the TD was also observed with the spring scale.

### III. RESULTS AND DISCUSSION

The battery and electronics package weighed 2.56 pounds (1.16 Kg), and the dimensions measured approximately 6 inches (15.24 cm) in width by 6 inches (15.24 cm) in height by 1.24 inches (3.17 cm) in thickness. Six cables or conductors came out of the pack. Each had a connector, one of which connected to the motor and another connected to the control switch. The control switch measured about 2 inches in diameter and 7/16 inch in thickness. A strain gage served to produce the proportional control feature. By applying a force through the cable the gage was deformed causing a resistance change proportional to the speed of the motor which operates the terminal device.

The cable force required to initiate movement of the motor shaft was found to be about 0.26 pound (120 grams). The maximum cable force corresponding to max. speed was 5.8 pounds (2.61 Kg). A force slightly above this was found to activate the microswitch for opening the terminal device.

During the evaluation there was a tendency for the sensitivity of the electronics to go off causing the terminal device to close and a loss in battery energy caused uncontrollable closing. The sensitivity had a limited adjustment, so it could be controlled to a degree. However, beyond a certain point of energy loss the sensitivity adjustment ceased to exist and set up a runaway condition.

A condition of over-grasp was apparent during operation of the control. This condition was inherent in the system because of the sequence of switching in crossing over the control region for closing the TD to reach the opening region. The crossover point between TD closing and TD opening was practically instantaneous and seemed much too sensitive for satisfactory operation by the amputee.

There was a minimal of cable excursion required to operate this control system and amounted to less than 1/32 inch including closing and opening the terminal device.

An apparent electrical failure of the system was cause for a premature discontinuance of the evaluation.

### IV. CONCLUSIONS & RECOMMENDATIONS

On the basis of this limited evaluation there were some significant observations made and while an apparent failure of the system precluded further investigations, it is felt that the following might be concluded with some added recommendations:

1. The pack containing the batteries and electronic components is quite bulky and in a state of general disarray with the numerous electrical cables exiting the pack. Consideration should be given to a re-design of the system with the idea of reducing the bulk and weight, re-packaging the electronics and eliminating some of the cables and connectors.

2. The concept of proportional control is very good and affords the amputee the ability to more precisely control his prosthesis.

3. The initial cable force is too low. This results in inadvertent operation of the prosthesis. A means for adjusting this force should be considered.

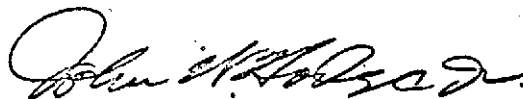
4. The crossover in the control switch between closing and opening of the TD produces an instantaneous change without warning to the amputee. Perhaps there should be a zone of no movement of the terminal device between the closing and opening positions.

5. The extremely low cable excursion is a good feature and means that the control can be operated with very little body movement. This should make the system applicable to those cases of extreme disabilities such as a shoulder disarticulation or fore quarter amputees.

6. There is an apparent current drain when the system is hooked up but not in use. There should be a means of deactivating the system when not in use without disconnecting all of the cables.

7. Low battery current produces an inability to stabilize the electronics circuitry resulting in slow but continuous operation of the terminal device causing possible jamming. A means for alleviating this condition could possibly be obtained at the same time a means is considered for deactivating the system when not in use.

Finally, while the amputee could operate the prosthesis with this control, there was insufficient testing on the amputee to determine a significant amount about his response to the system.



JOHN W. HODGE, Jr.  
Acting Chief,  
Engr Eval Branch



#### DISSEMINATION OF INFORMATION

In addition to the news releases described under Phase IV of this contract, a movie has been prepared and duplicated, and is available for loan upon request. The movie was made at Rancho Los Amigos Hospital with the patient used to develop and test the entire system in our clinical evaluations. The activities include the use of a hand drill and other activities of daily life.

A distribution list of about 100 persons will be selected to receive a direct mailing of this final report. These individuals will be those in the industry who could implement the use of this equipment on patients directly and make individual evaluations of the entire systems as used in their particular applications.

## S U M M A R Y

The goals of this project were (1) to develop a mechanical hook with a trigger finger to activate power tools, (2) to develop transducers for its application to patients, and (3) to design and develop a proportional control system -- all based on present NASA technology and equipment modified for patient application.

The equipment has all been designed and fabricated, and has undergone clinical testing with the Communications, Power & Control Engineering laboratory at Rancho Los Amigos Hospital. These applications included both single and multiple channel units for orthotic and prosthetic purposes. In addition, clinical evaluations of the proportional control systems have been made at three different Centers in the United States. It is anticipated that one additional multiple channel system will be fitted at Rancho for continued evaluation.

## CONCLUSIONS AND RECOMMENDATIONS

Based on clinical evaluations done at this facility, the powered hook with the trigger finger appears to be a useful adaptation of a terminal device for an amputee when performing vocational activities involving the use of a powered tool requiring a trigger control. Further evaluation at a vocational rehabilitation center for amputees might indicate to what degree it is practical. The device indicates at this point that it should be an add-on or replacement terminal device for the ease of volitional control of a specific task. By no means can it be considered as a factotum. If one considers the powered hook itself without the trigger finger mechanism, there is no doubt that it is a very useful and functional device where external power for general prehensile purposes is required. Since it is capable of a prehensile force of 25 pounds, it is applicable to an amputee doing fairly heavy physical work.

The proportional control system which includes both the transducers and amplifiers and appears to have widespread application for control of any external power, whether it be in the orthotic or prosthetic field. These units work extremely well and, in their present use in permanent fittings, time testing for reliability will be achieved.

It is recommended that there be continued follow-up on the existing fittings, with assistance to centers who require this type of equipment for their patients. This assistance may consist of providing hardware with guidance for fitting each patient.

A P P E N D I X

February 28, 1973

Mr. Thomas N. Lauko  
Bioengineering Project Director  
The Burke Rehabilitation Center  
785 Mamaroneck Avenue  
White Plains, New York 10605

Dear Mr. Lauko:

In accordance with our telephone conversation, we would like to establish guidelines for the evaluation to be performed with this equipment. Size, weight, cosmesis, wires, etc., are not a part of this evaluation. All emphasis will be placed on the transducer and amplifier and their performance.

#### Procedure

1. Select a patient using external power (12 volt unit) either on a prosthesis or on an orthotic device with an on/off switch control. Patient control capabilities should fit required transducer action.
2. Select at least three activities where comparisons can be made between the two control modes. An example - a prehensil device may be to grasp something critical where fracture or damage would occur if control capability is not available.
3. Allow a minimum of one hour practice of the task with each control mode.
4. Make three performances of each task using time, error in position, etc., as your yardstick to measure performance.
5. Evaluate and summarize.



Mr. Thomas N. Lajko  
Page 2

**Report**

The report can be in the form of a letter giving the following information:

1. Patient identification with diagnosis and onset.
2. Short description of his permanent equipment he is presently using and how long.
3. Describe the tasks.
4. Summarize results.
5. Make recommendations.

Should you encounter any difficulty or require any further assistance, do not hesitate to communicate with me.

Yours truly,

Andrew Karchak, Jr., Project Director  
Communication, Power & Control Engineering

mrc

Enclosure: Equipment Description and Operation

## EQUIPMENT DESCRIPTION AND OPERATION

1. LINEAR TRANSDUCER
2. BATTERY CHARGER
3. BATTERY AND AMPLIFIER PACK

### EQUIPMENT DESCRIPTION

#### Linear Transducer

The linear transducer is a three-position control device made to be activated by a unidirectional motion with a spring return. The first position is an off or hold position and is associated with the normal or relaxed state of the operator. The second position operates over several thousands of an inch of linear displacement which deflects a cantilever beam. The beam is equipped with solid state strain gages which provide a variable resistance which is proportional to the displacement. The third position is reached when linear displacement of the beam reaches the end of its travel and trips a micro switch which provides an on/off channel of control. This type of transducer is ideal where only unidirectional motion is available or desirable such as in a shoulder harness. The signal provided is most ideal for a prehension device since the proportional control channel can be used for closing and the on/off channel for opening.

#### Battery Charger

The battery charger is a standard 12 volt 1 amp charger which has been modified with the addition of a current limiting resistor which then makes it possible to charge the NICKEL CADMIUM batteries at their recommended charging rate. This unit has two outlets to charge two separate batteries simultaneously.

#### Battery and Amplifier Pack

The proportional control amplifier and two batteries are housed in one packet. Interconnection of these units is accomplished by the connection of like plugs hanging out of the units.

### OPERATION

All plugs in the battery and amplifier pack should be disconnected when not in use. It would be advisable to charge the batteries overnight before using. Plug the two charger outputs to the battery and amplifier pack and plug in charger overnight. Disconnect the next day. To operate the system, plug together all like plugs on amplifier and battery pack. Next, plug transducer into three-prong Jones plug. Plug in remaining two-prong Jones plug to motor to be operated. When the total system is hooked together and, if nothing occurs, the amplifier is in balance. If a ticking sound occurs accompanied by a slow motion of the motor, the amplifier bridge is out of balance and can be corrected by adjusting screw through a hole in the amplifier case. If or when amplifier is balanced, pick up the transducer and begin to activate the unit. Initial displacement will begin to turn the motor slowly and will increase in speed as you pull harder until maximum velocity is reached. Increased displacement will then trip the micro switch and reverse the motor at full velocity. Total relaxation of the transducer will become off or hold depending on the joint activity.

THE BURKE REHABILITATION CENTER  
WHITE PLAINS, NEW YORK  
10605  
WHITE PLAINS 8-0050

March 28, 1973

Mr. Andrew Karchak, Jr., Project Director  
Communication, Power & Control Engineering  
Rancho Los Amigos Hospital  
12826 Hawthorn Street  
Downey, California 90242

Dear Mr. Karchak:

We have completed our evaluation of the proportional control unit which you sent us. Two patients were selected for the evaluation. I have tried to follow your guidelines in evaluating each patient and in presenting our observations.

We very much appreciate the opportunity to evaluate your proportional control. I know that the first patient described would prefer this control to the on/off. I hope that through these efforts such a control will soon be easily available for needy patients. Should you need elaboration on any of the points made here, please contact us.

Thank you again for allowing us to participate in this most interesting project.

Yours very truly,

*Frederick W. Werner*

Frederick W. Werner  
Department of Bioengineering

February 28, 1973

Mr. Lloyd L. Salisbury  
Chief, Biomedical Electronics  
USAMBRL - Walter Reed Army Medical Center  
Washington, D.C. 20012

Dear Mr. Salisbury:

In accordance with our telephone conversation, we would like to establish guidelines for the evaluation to be performed with this equipment. Size, weight, cosmesis, wires, etc., are not part of this evaluation. All emphasis will be placed on the transducer and amplifier and their performance.

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Communication, Power & Control Engineering

mrc

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DEPARTMENT OF THE ARMY  
US ARMY MEDICAL BIOENGINEERING RESEARCH AND  
DEVELOPMENT LABORATORY

FORT DETRICK, FREDERICK, MARYLAND 21701

IN REPLY REFER TO:

SGRD-UBE-B

29 October 1973

Mr. Andrew Karchak, Jr.  
Project Director  
Communication, Powered Control Engineering  
Rancho Los Amigos Hospital  
Attending Staff Association  
12826 Hawthorn Street  
Downey, California 90242

Dear Andy:

Inclosed are a report and photographs of the proportional controller. I am very sorry for the delay, next time I promise not to take so long. The Army hand that we used is an electrified APRL 44 hand. We removed the automatic control feature and left only the switch which limits the maximum opening.

We had trouble with the system as is mentioned. The first was one of the batteries supplying the electronics discharged completely even though the others were up to charge. Charging that one separately appeared to fix it. The next trouble appears to be in the electronics and keeps the open relay energized. Without a circuit diagram I did not go into the circuit. I will return the unit to you in a separate package.

We feel that the open and close force levels are too close and will produce inadvertent opening when maximum closing force is desired. The connector arrangement is very cumbersome, one miniature multi contact is desirable. The package is large and bulky, but the only reduction in size immediately apparent is miniaturization of the electronics and elimination of the casing which would not be too great if you have to stay with the amper/hour rating of the batteries.

Despite these shortcomings the unit looks good and will provide the patient with an effective method of proportional control.

Sincerely,

Incls  
as

LLOYD SALISBURY  
Chief, Biosystems Control Branch  
Engineering Division

February 28, 1973

Mr. Thomas Pirrello  
Veterans Administration  
252 Seventh Avenue  
New York, New York 10001

Dear Mr. Pirrello:

In accordance with our telephone conversation, we would like to establish guidelines for the evaluation to be performed with this equipment. Size, weight, cosmesis, wires, etc., are not part of this evaluation. All emphasis will be placed on the transducer and amplifier and their performance.

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2. Select at least three activities where comparisons can be made between the two control modes. An example - a prehensil device may be to grasp something critical where fracture or damage would occur if control capability is not available.
3. Allow a minimum of one hour practice of the task with each control mode.
4. Make three performances of each task using time, error in position, etc., as your yardstick to measure performance.
5. Evaluate and summarize.

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**Report**

The report can be in the form of a letter giving the following information:

1. Patient identification with diagnosis and onset.
2. Short description of his permanent equipment he is presently using and how long.
3. Describe the tasks.
4. Summarize results
5. Make recommendations

Should you encounter any difficulty or require any further assistance, do not hesitate to communicate with me.

Yours truly,

Andrew Karchak, Jr., Project Director  
Communication, Power & Control Engineering

mrc

Enclosure: Equipment Description and Operation

## EQUIPMENT DESCRIPTION AND OPERATION

1. LINEAR TRANSDUCER
2. BATTERY CHARGER
3. BATTERY AND AMPLIFIER PACK

### EQUIPMENT DESCRIPTION

#### Linear Transducer

The linear transducer is a three-position control device made to be activated by a unidirectional motion with a spring return. The first position is an off or hold position and is associated with the normal or relaxed state of the operator. The second position operates over several thousands of an inch of linear displacement which deflects a cantilever beam. The beam is equipped with solid state strain gages which provide a variable resistance which is proportional to the displacement. The third position is reached when linear displacement of the beam reaches the end of its travel and trips a micro switch which provides an on/off channel of control. This type of transducer is ideal where only unidirectional motion is available or desirable such as in a shoulder harness. The signal provided is most ideal for a prehension device since the proportional control channel can be used for closing and the on/off channel for opening.

#### Battery Charger

The battery charger is a standard 12 volt 1 amp charger which has been modified with the addition of a current limiting resistor which then makes it possible to charge the NICKEL CADMIUM batteries at their recommended charging rate. This unit has two outlets to charge two separate batteries simultaneously.

#### Battery and Amplifier Pack

The proportional control amplifier and two batteries are housed in one packet. Interconnection of these units is accomplished by the connection of like plugs hanging out of the units.

### OPERATION

All plugs in the battery and amplifier pack should be disconnected when not in use. It would be advisable to charge the batteries overnight before using. Plug the two charger outputs to the battery and amplifier pack and plug in charger overnight. Disconnect the next day. To operate the system, plug together all like plugs on amplifier and battery pack. Next, plug transducer into three-prong Jones plug. Plug in remaining two-prong Jones plug to motor to be operated. When the total system is hooked together and, if nothing occurs, the amplifier is in balance. If a ticking sound occurs accompanied by a slow motion of the motor, the amplifier bridge is out of balance and can be corrected by adjusting screw through a hole in the amplifier case. If or when amplifier is balanced, pick up the transducer and begin to activate the unit. Initial displacement will begin to turn the motor slowly and will increase in speed as you pull harder until maximum velocity is reached. Increased displacement will then trip the micro switch and reverse the motor at full velocity. Total relaxation of the transducer will become off or hold depending on the joint activity.